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Besoli et al.

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(54) **PHASED ARRAY ANTENNA PANEL WITH CONFIGURABLE SLANTED ANTENNA ROWS**

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CPC ***H01Q 21/22*** (2013.01); ***H01Q 1/241*** (2013.01); ***H01Q 3/06*** (2013.01); ***H01Q 3/26*** (2013.01);
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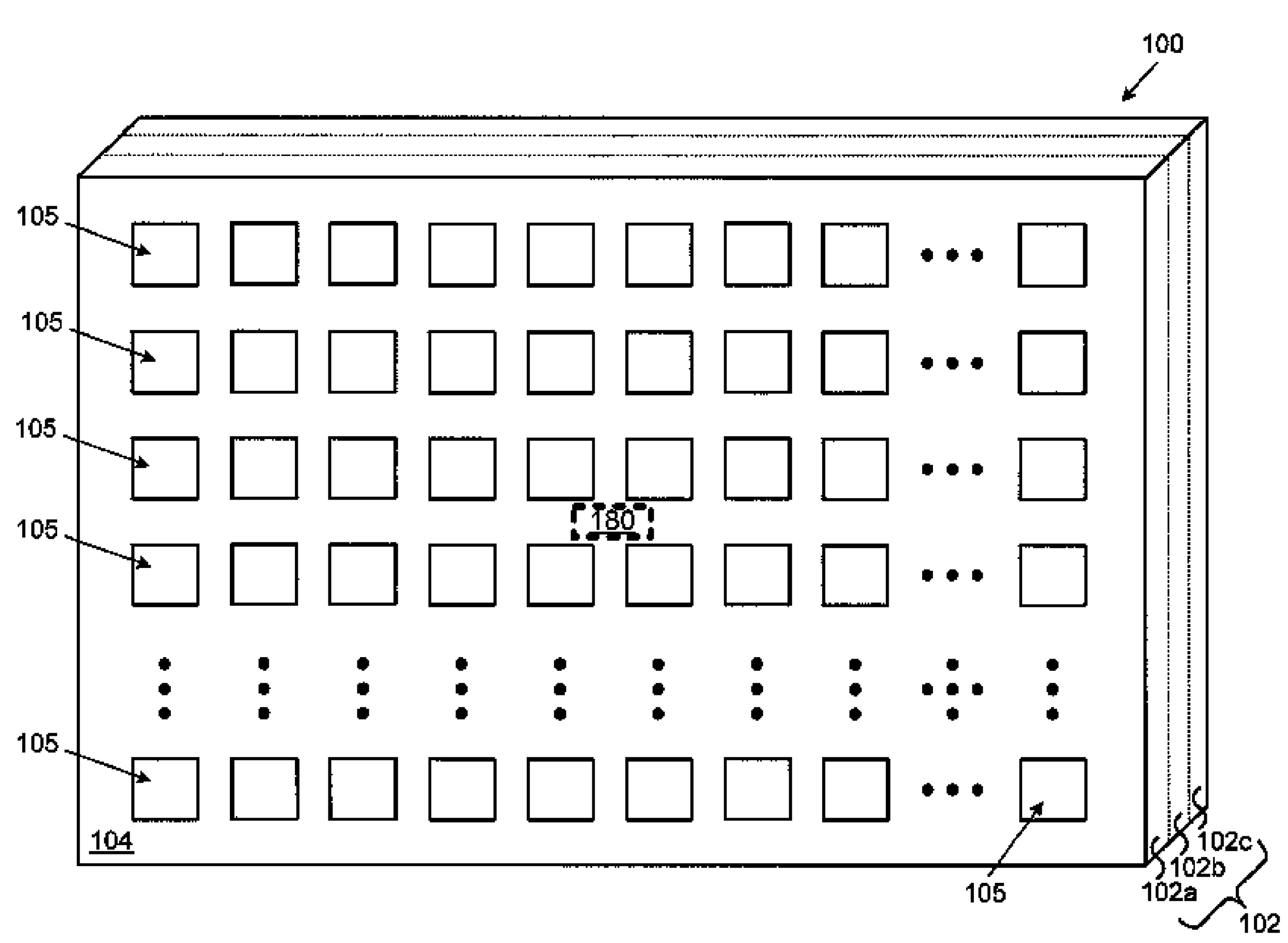
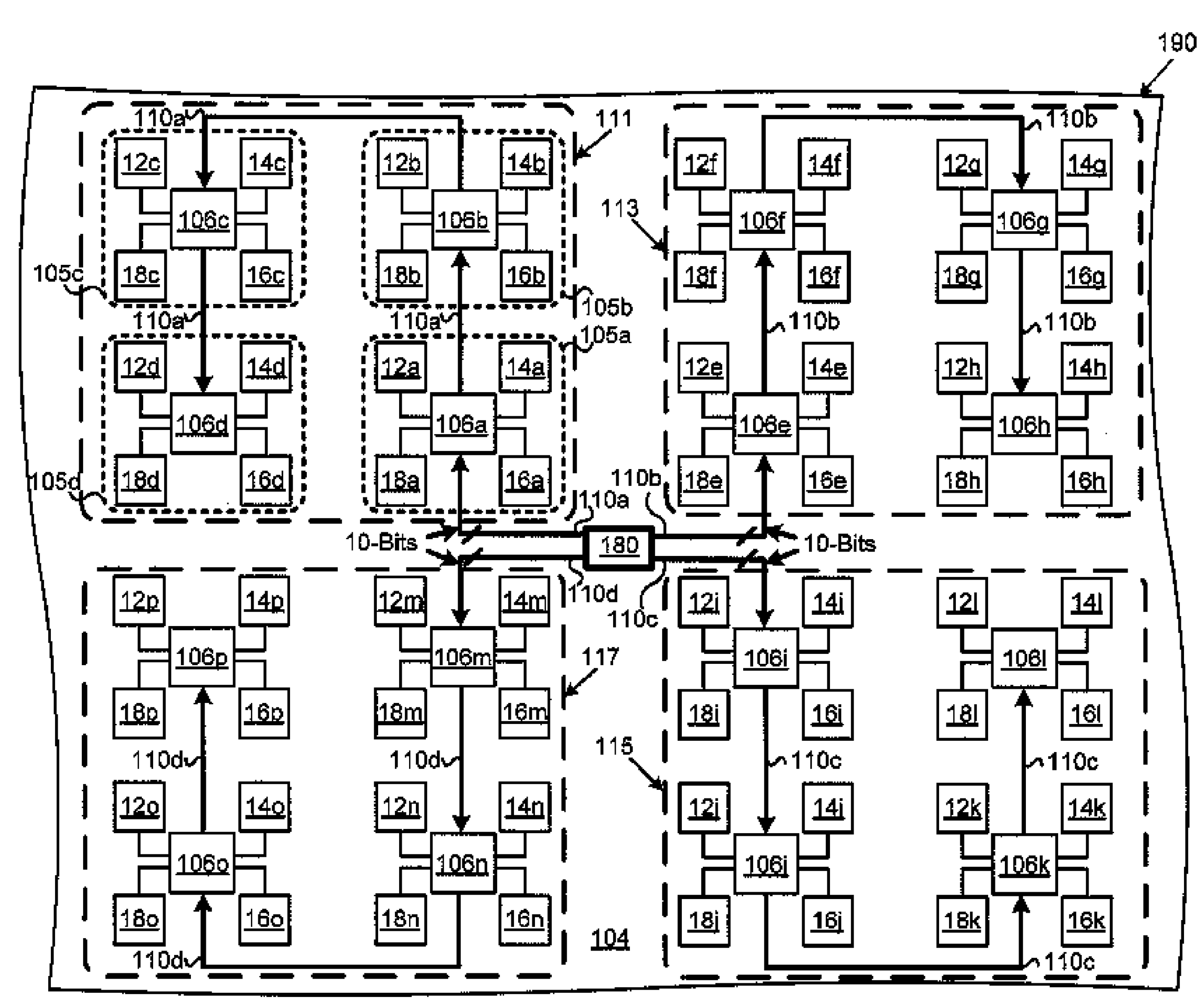
(57) **ABSTRACT**

A phased array antenna panel includes a plurality of antennas and a master chip. The antennas are arranged in a plurality of antenna rows. At least one antenna row in the plurality of antenna rows is configured to be slanted in a desired angle based on signals received from the master chip. Additionally, the phased array antenna panel can include a plurality of row-shaped lenses. At least one row-shaped lens has a corresponding antenna row, and is configured to increase a gain of the corresponding antenna row. The row-shaped lens can increase a total gain of the phased array antenna panel. The row-shaped lens is configured to be slanted in a desired angle based on signals received from the master chip.

10 Claims, 11 Drawing Sheets





(51) **Int. Cl.**

H01Q 3/06	(2006.01)
H01Q 3/26	(2006.01)
H01Q 19/06	(2006.01)
H01Q 21/00	(2006.01)
H01Q 21/06	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 19/06*** (2013.01); ***H01Q 21/0006*** (2013.01); ***H01Q 21/065*** (2013.01)

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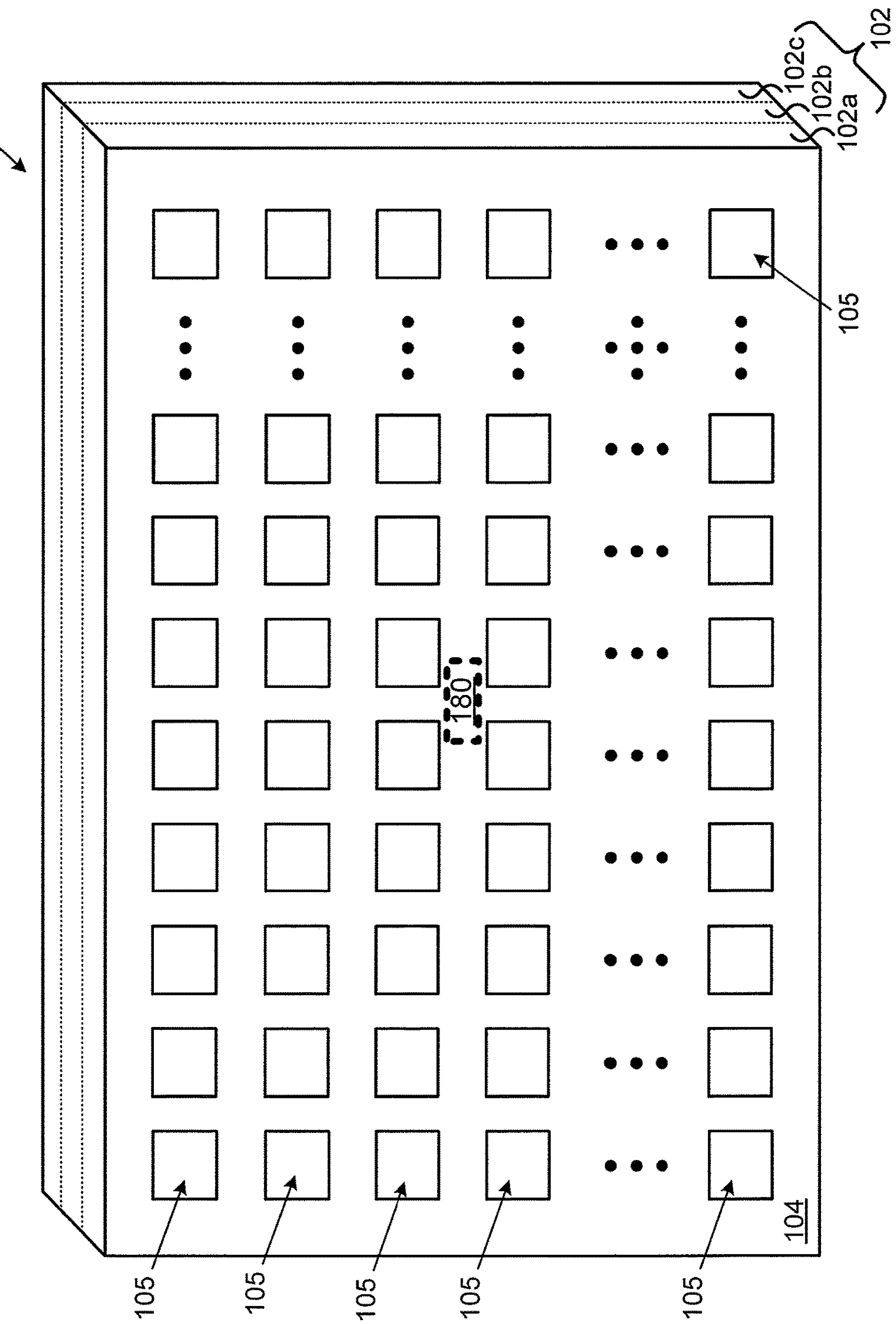
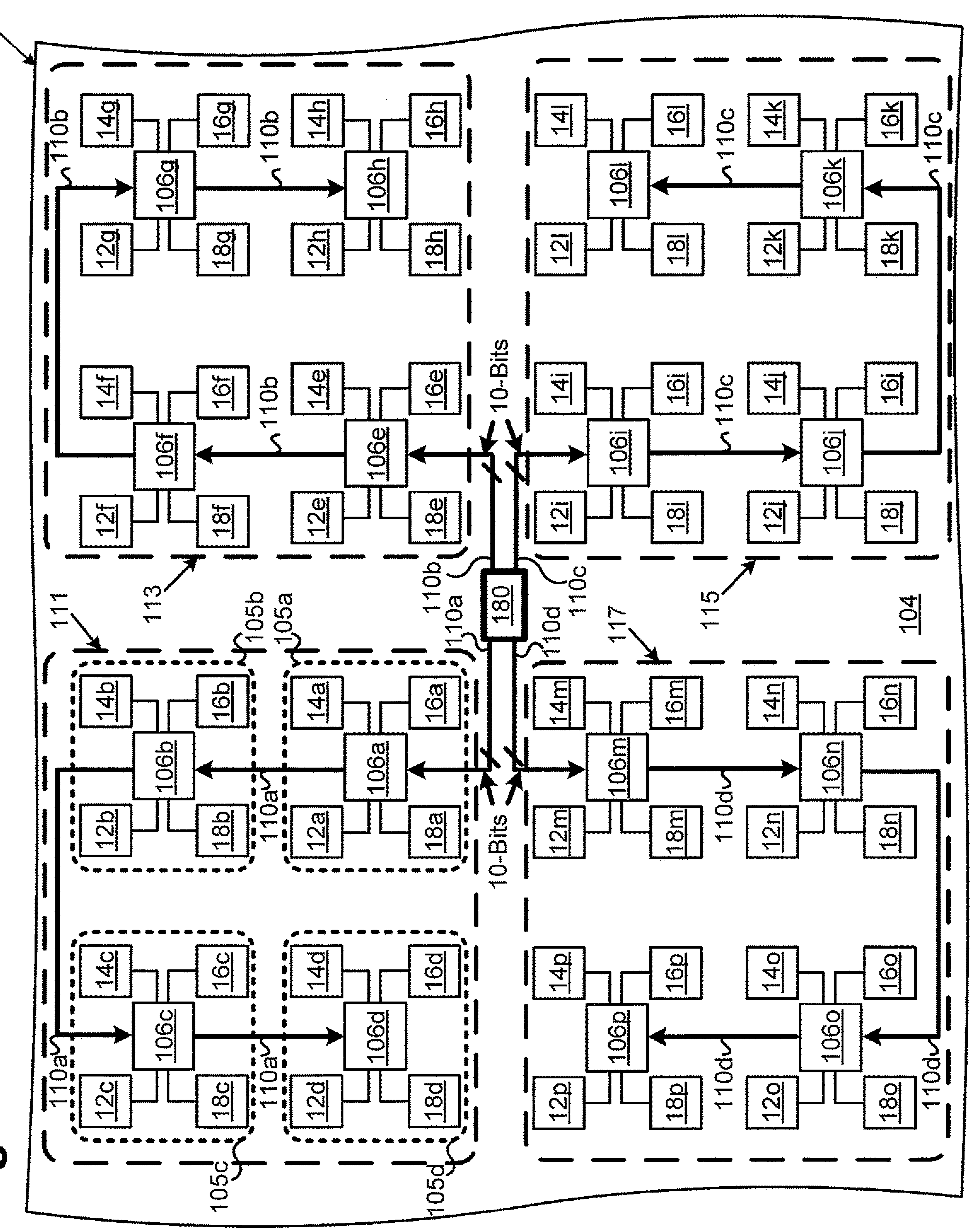


Fig. 1A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104
111
113
115
117
180
10-Bits
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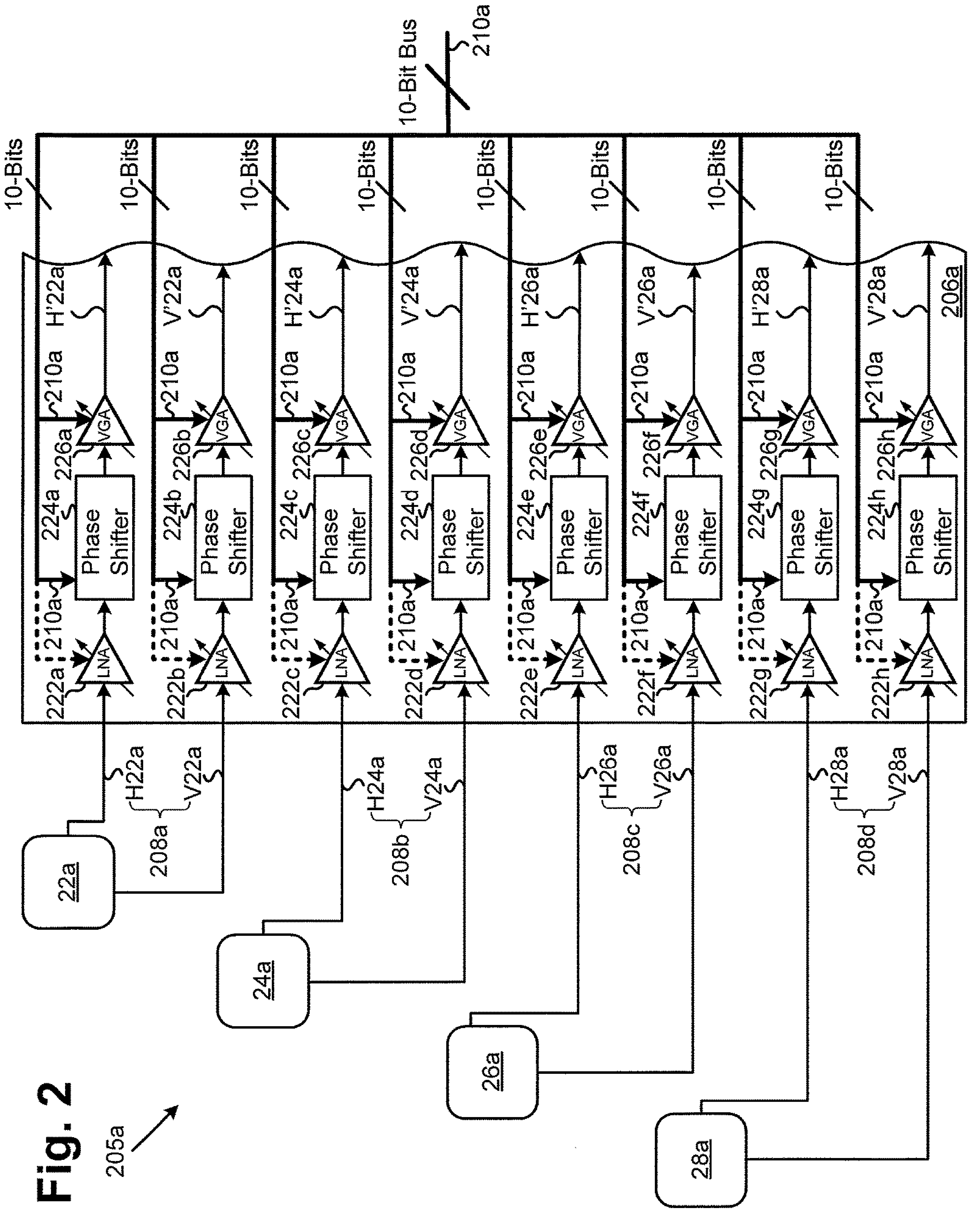
106b
106c
106d
106e
106f
106g
106h
106i
106j
106k
106l
106m
106n
106o
106p
12a 14a 16a 18a
12b 14b 16b 18b
12c 14c 16c 18c
12d 14d 16d 18d
12e 14e 16e 18e
12f 14f 16f 18f
12g 14g 16g 18g
12h 14h 16h 18h
12i 14i 16i 18i
12j 14j 16j 18j
12k 14k 16k 18k
12l 14l 16l 18l
12m 14m 16m 18m
12n 14n 16n 18n
12o 14o 16o 18o
12p 14p 16p 18p

Fig. 1B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10-Bits
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V'22a
H'24a
V'24a
H'26a
V'26a
H'28a
V'28a
206a
VGA
226a
226b
226c
226d
226e
226f
226g
226h
Phase Shifter
224a
224b
224c
224d
224e
224f
224g
224h
LNA
222a
222b
222c
222d
222e
222f
222g
222h
H22a
V22a
H24a
V24a
H26a
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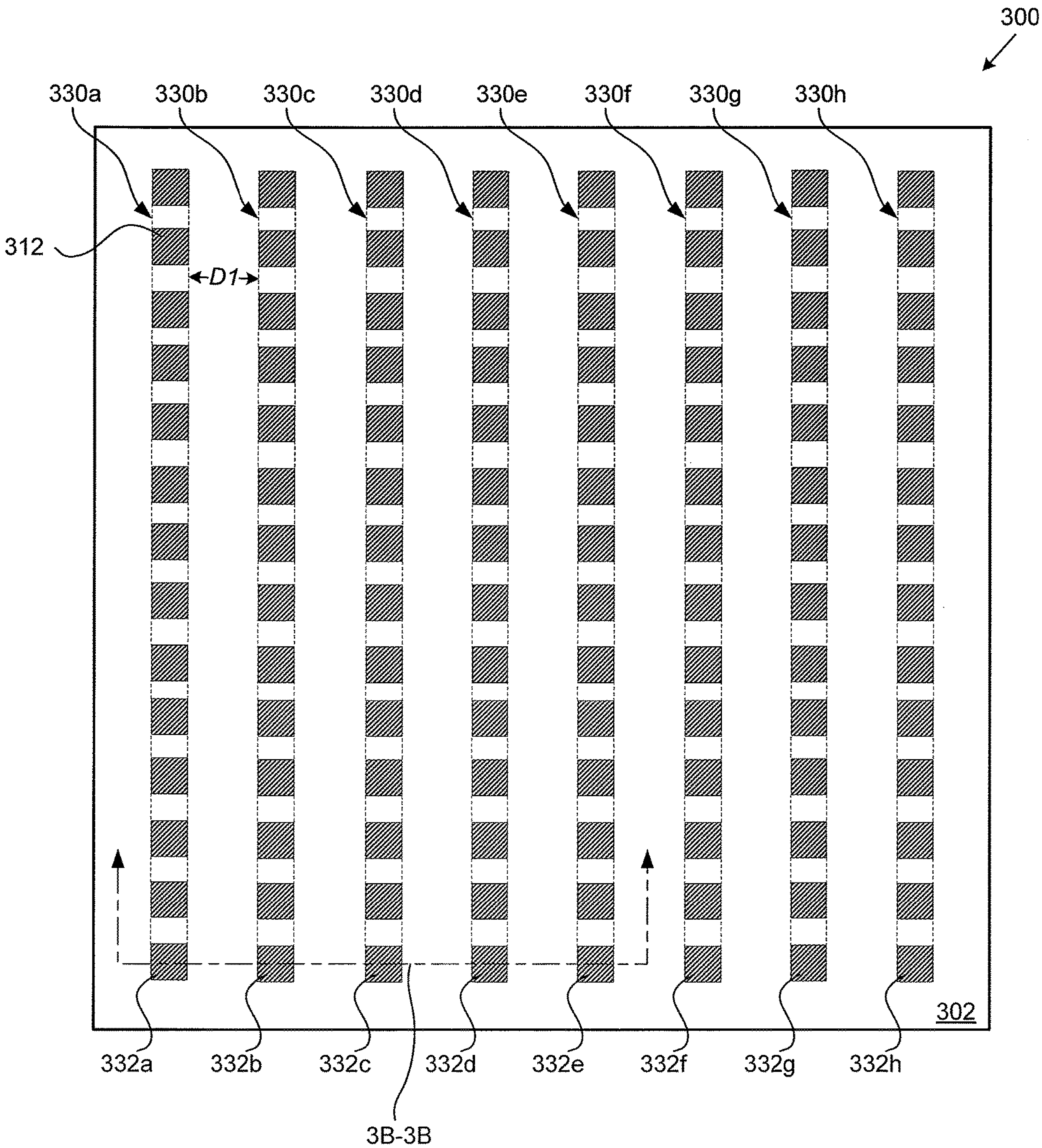
26a
28a
205a

Fig. 2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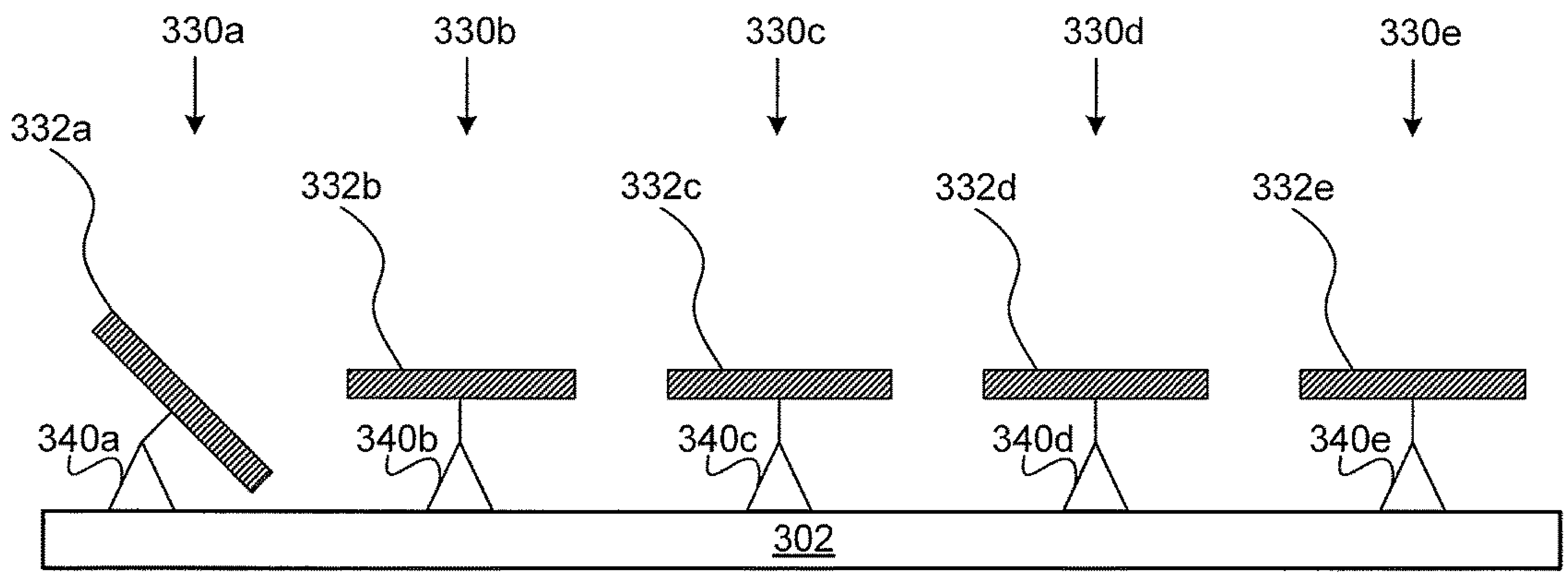
330c
330d
330e
330f
330g
330h
312
D1
302
332a
332b
332c
332d
332e
332f
332g
332h
3B-3B

Fig. 3A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330b
330c
330d
330e
332a
332b
332c
332d
332e
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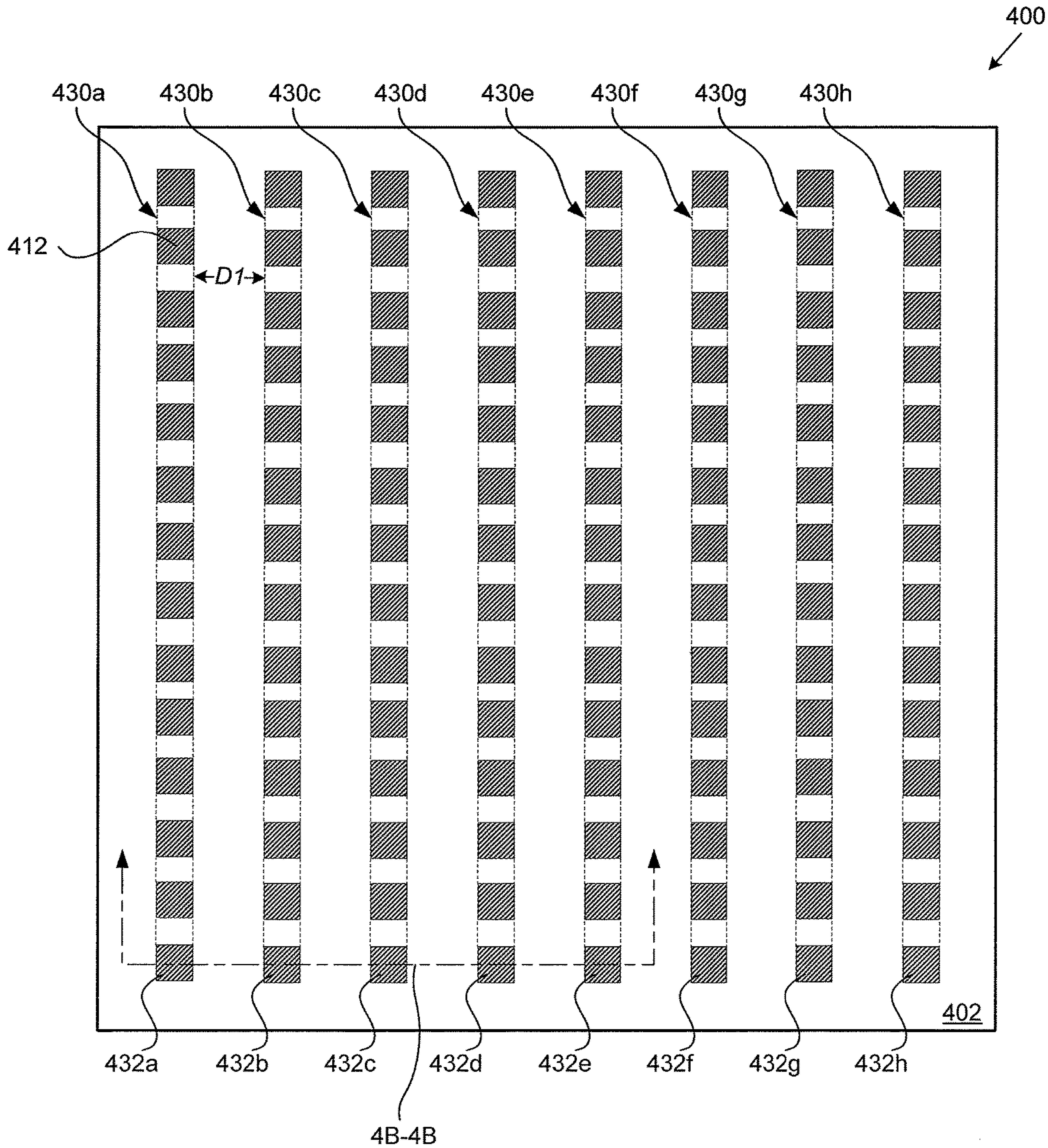
340c
340d
340e
302

Fig. 3B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430d
430e
430f
430g
430h
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D1
402
432a
432b
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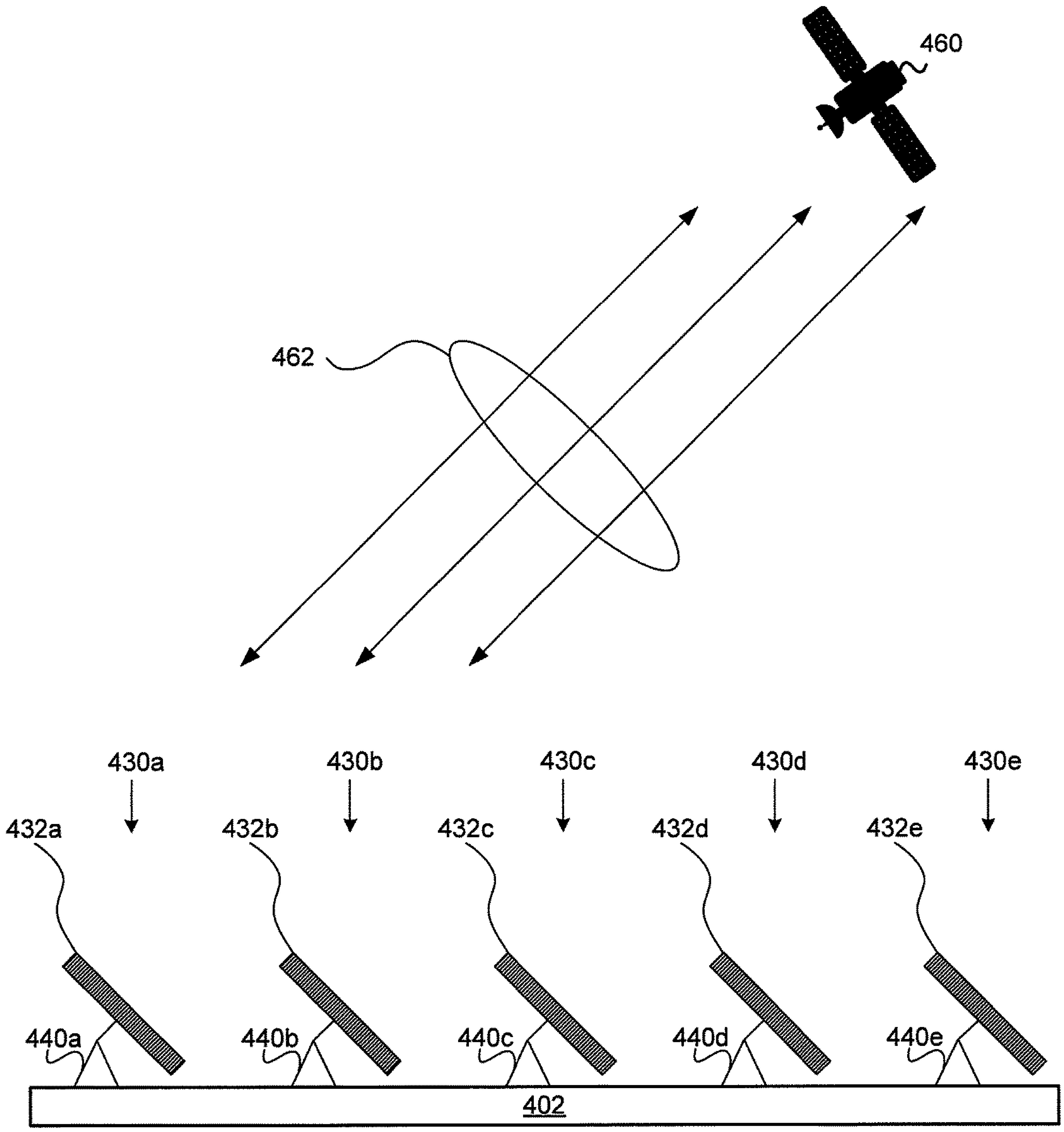
432d
432e
432f
432g
432h
4B-4B

Fig. 4A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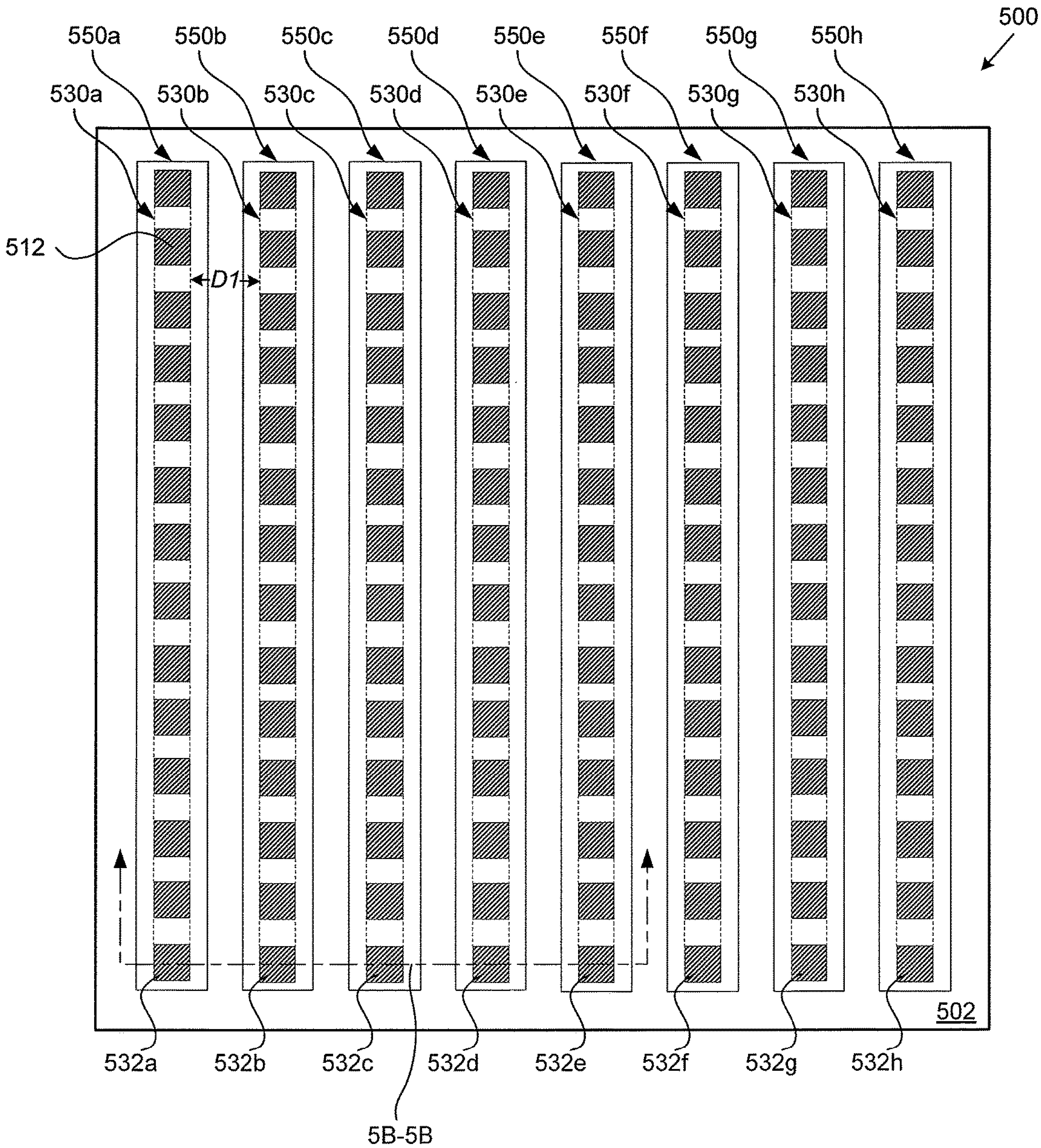
440d
440e
402

Fig. 4B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550h
530a
530b
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530e
530f
530g
530h
512
D1
502
532a
532b
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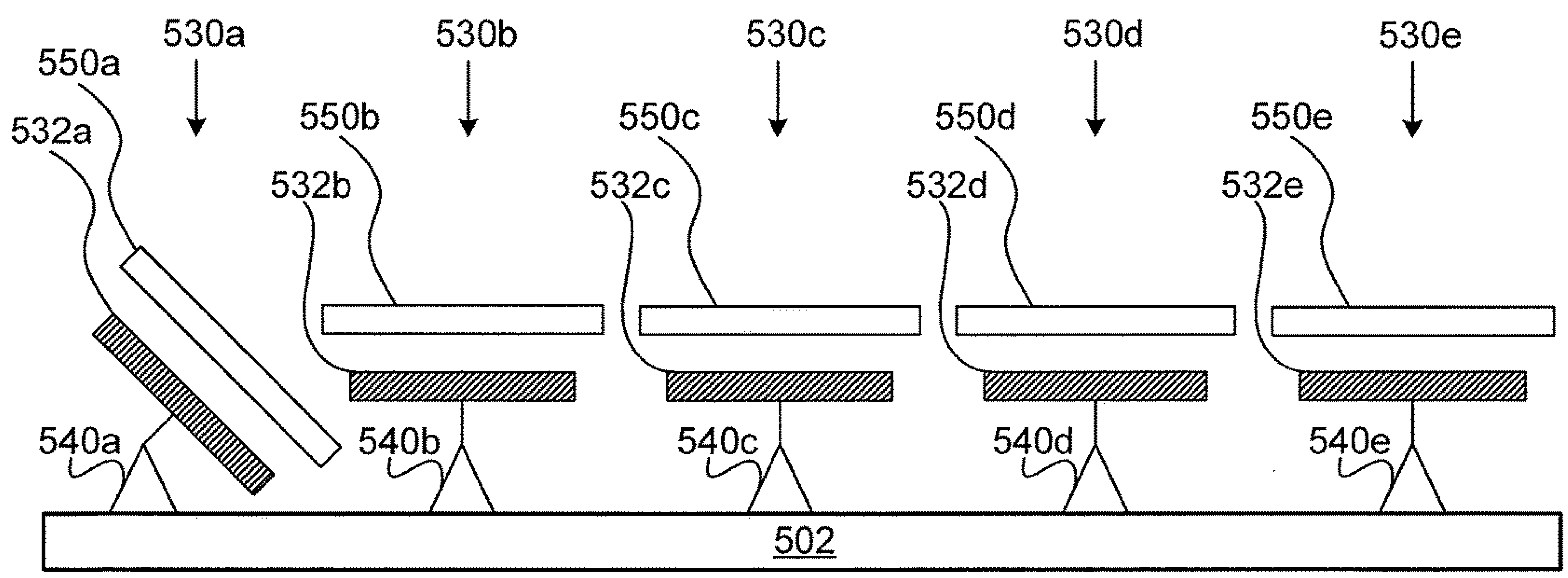
532d
532e
532f
532g
532h
5B-5B

Fig. 5A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550b
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532d
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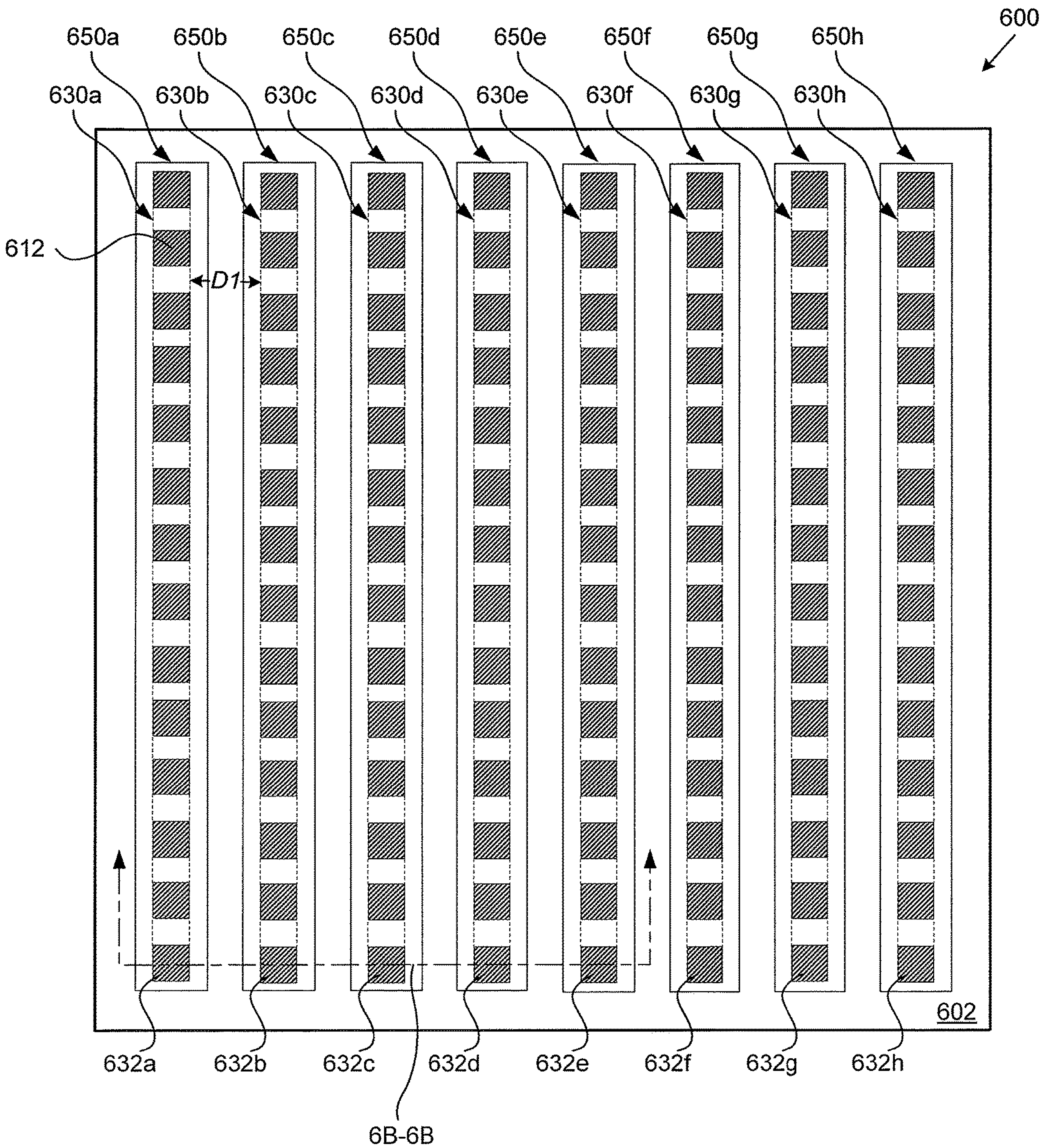
540d
540e
502

Fig. 5B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650b
650c
650d
650e
650f
650g
650h
630a
630b
630c
630d
630e
630f
630g
630h
612
D1
602
632a
632b
632c
632d
632e
632f
632g
632h
6B-6B

Fig. 6A

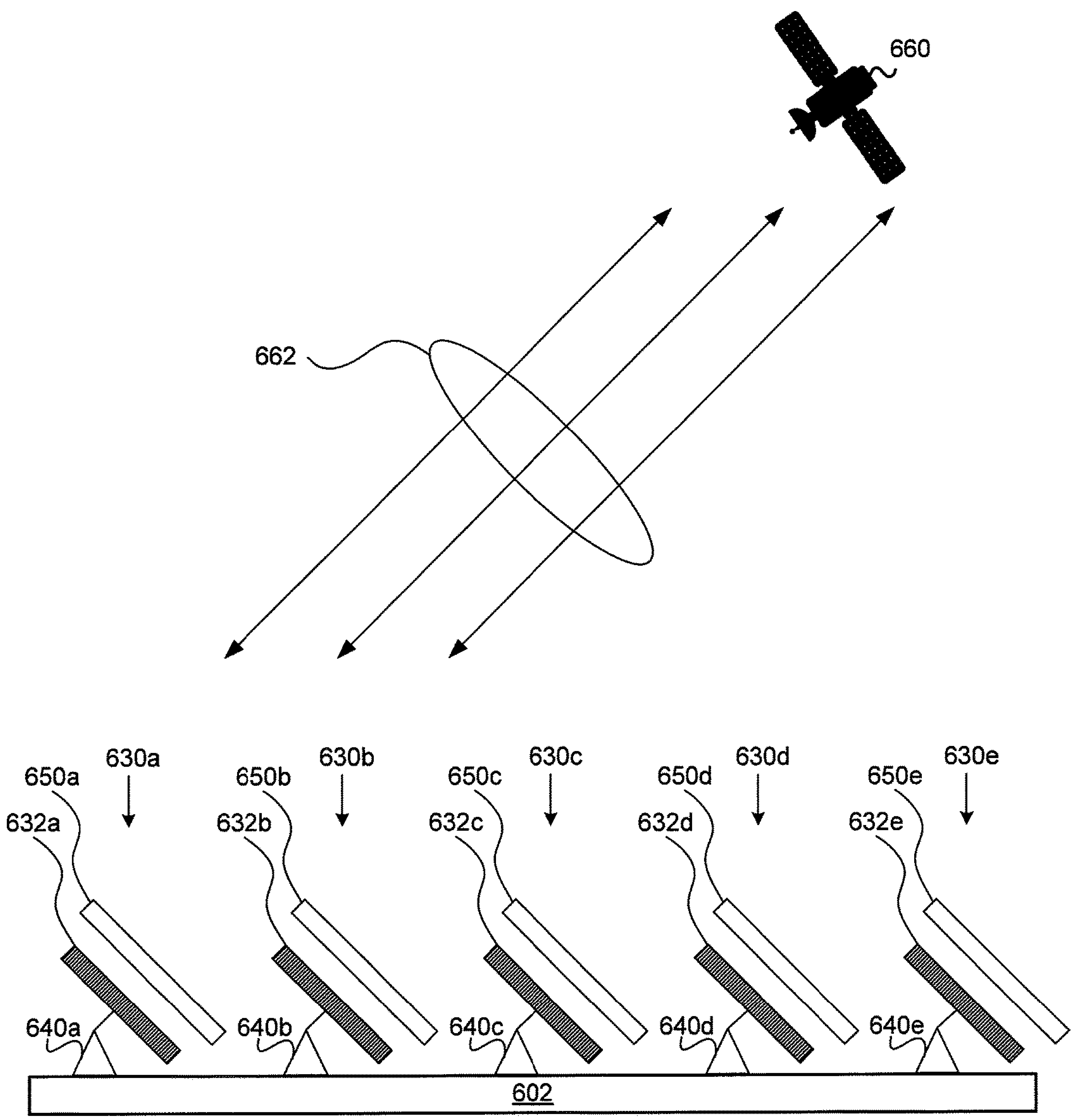
660
662
630a
630b
630c
630d
630e
650a
650b
650c
650d
650e
632a
632b
632c
632d
632e
640a
640b
640c
640d
640e
602

Fig. 6B

PHASED ARRAY ANTENNA PANEL WITH CONFIGURABLE SLANTED ANTENNA ROWS

RELATED APPLICATION(S)

The present application is related to U.S. patent application Ser. No. 15/225,071, filed on Aug. 1, 2016, and titled "Wireless Receiver with Axial Ratio and Cross-Polarization Calibration," and U.S. patent application Ser. No. 15/225,523, filed on Aug. 1, 2016, and titled "Wireless Receiver with Tracking Using Location, Heading, and Motion Sensors and Adaptive Power Detection," and U.S. patent application Ser. No. 15/226,785, filed on Aug. 2, 2016, and titled "Large Scale Integration and Control of Antennas with Master Chip and Front End Chips on a Single Antenna Panel," and U.S. patent application Ser. No. 15/255,656, filed on Sep. 2, 2016, and titled "Novel Antenna Arrangements and Routing Configurations in Large Scale Integration of Antennas with Front End Chips in a Wireless Receiver," and U.S. patent application Ser. No. 15/256,038 filed on Sep. 2, 2016, and titled "Transceiver Using Novel Phased Array Antenna Panel for Concurrently Transmitting and Receiving Wireless Signals," and U.S. patent application Ser. No. 15/256,222 filed on Sep. 2, 2016, and titled "Wireless Transceiver Having Receive Antennas and Transmit Antennas with Orthogonal Polarizations in a Phased Array Antenna Panel," and U.S. patent application Ser. No. 15/278,970 filed on Sep. 28, 2016, and titled "Low-Cost and Low-Loss Phased Array Antenna Panel," and U.S. patent application Ser. No. 15/279,171 filed on Sep. 28, 2016, and titled "Phased Array Antenna Panel Having Cavities with RF Shields for Antenna Probes," and U.S. patent application Ser. No. 15/279,219 filed on Sep. 28, 2016, and titled "Phased Array Antenna Panel Having Quad Split Cavities Dedicated to Vertical-Polarization and Horizontal-Polarization Antenna Probes," and U.S. patent application Ser. No. 15/335,034 filed on Oct. 26, 2016, and titled "Lens-Enhanced Phased Array Antenna Panel." The disclosures of all of these related applications are hereby incorporated fully by reference into the present application.

BACKGROUND

Phased array antenna panels with large numbers of antennas and front end chips integrated on a single board are being developed in view of higher wireless communication frequencies being used between a satellite transmitter and a wireless receiver, and also more recently in view of higher frequencies used in the evolving 5G wireless communications (5th generation mobile networks or 5th generation wireless systems). Phased array antenna panels are capable of beamforming by phase shifting and amplitude control techniques, and without physically changing direction or orientation of the phased array antenna panels, and without a need for mechanical parts to effect such changes in direction or orientation.

The ability of a phase array antenna panel to scan in a variety of directions is critical in establishing reliable wireless communications. The directionality of a phased array antenna panel can be increased by utilizing more antennas, and more phase shifters and front end chips. However, due to cost and complexity, this approach can be impractical. Thus, there is a need in the art to increase the directionality of a wireless receiver employing a phased array antenna panel without increasing the number of antennas, phase shifters or front end chips of the phased array antennal panel.

SUMMARY

The present disclosure is directed to phased array antenna panels with configurable slanted antenna rows, substantially as shown in and/or described in connection with at least one of the figures, and as set forth in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a perspective view of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **1**B illustrates a layout diagram of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **2** illustrates a functional block diagram of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **3**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **3**B illustrates a cross-sectional view of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **4**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **4**B illustrates a cross-sectional view of a portion of an exemplary phased array antenna panel according to one implementation of the present application.

FIG. **5**A illustrates a top view of a portion of an exemplary lens-enhanced phased array antenna panel according to one implementation of the present application.

FIG. **5**B illustrates a cross-sectional view of a portion of an exemplary lens-enhanced phased array antenna panel according to one implementation of the present application.

FIG. **6**A illustrates a top view of a portion of an exemplary lens-enhanced phased array antenna panel according to one implementation of the present application.

FIG. **6**B illustrates a cross-sectional view of a portion of an exemplary lens-enhanced phased array antenna panel according to one implementation of the present application.

DETAILED DESCRIPTION

The following description contains specific information pertaining to implementations in the present disclosure. The drawings in the present application and their accompanying detailed description are directed to merely exemplary implementations. Unless noted otherwise, like or corresponding elements among the figures may be indicated by like or corresponding reference numerals. Moreover, the drawings and illustrations in the present application are generally not to scale, and are not intended to correspond to actual relative dimensions.

FIG. **1**A illustrates a perspective view of a portion of an exemplary phased array antenna panel according to one implementation of the present application. As illustrated in FIG. **1**A, phased array antenna panel **100** includes substrate **102** having layers **102***a*, **102***b*, and **102***c*, front surface **104** having front end units **105**, and master chip **180**. In the present implementation, substrate **102** may be a multi-layer printed circuit board (PCB) having layers **102***a*, **102***b*, and **102***c*. Although only three layers are shown in FIG. **1**A, in another implementation, substrate **102** may be a multi-layer PCB having greater or fewer than three layers.

As illustrated in FIG. **1**A, front surface **104** having front end units **105** is formed on top layer **102***a* of substrate **102**. In one implementation, substrate **102** of phased array antenna panel **100** may include 500 front end units **105**, each having a radio frequency (RF) front end circuit connected to a plurality of antennas (not explicitly shown in FIG. **1**A). In one implementation, phased array antenna panel **100** may include 2000 antennas on front surface **104**, where each front end unit **105** includes four antennas connected to an RF front end circuit (not explicitly shown in FIG. **1**A).

In the present implementation, master chip **180** may be formed in layer **102***c* of substrate **102**, where master chip **180** may be connected to front end units **105** on top layer **102***a* using a plurality of control buses (not explicitly shown in FIG. **1**A) routed through various layers of substrate **102**. In the present implementation, master chip **180** is configured to provide phase shift and amplitude control signals from a digital core in master chip **180** to the RF front end chips in each of front end units **105** based on signals received from the antennas in each of front end units **105**.

FIG. **1**B illustrates a layout diagram of a portion of an exemplary phased array antenna panel according to one implementation of the present application. For example, layout diagram **190** illustrates a layout of a simplified phased array antenna panel on a single printed circuit board (PCB), where master chip **180** is configured to drive in parallel four control buses, e.g., control buses **110***a*, **110***b*, **110***c*, and **110***d*, where each control bus is coupled to a respective antenna segment, e.g., antenna segments **111**, **113**, **115**, and **117**, where each antenna segment has four front end units, e.g., front end units **105***a*, **105***b*, **105***c*, and **105***d* in antenna segment **111**, where each front end unit includes an RF front end chip, e.g., RF front end chip **106***a* in front end unit **105***a*, and where each RF front end chip is coupled to four antennas, e.g., antennas **12***a*, **14***a*, **16***a*, and **18***a* coupled to RF front end chip **106***a* in front end unit **105***a*.

As illustrated in FIG. **1**B, front surface **104** includes antennas **12***a* through **12***p*, **14***a* through **14***p*, **16***a* through **16***p*, and **18***a* through **18***p*, collectively referred to as antennas **12-18**. In one implementation, antennas **12-18** may be configured to receive and/or transmit signals from and/or to one or more commercial geostationary communication satellites or low earth orbit satellites.

In one implementation, for a wireless transmitter transmitting signals at 10 GHz (i.e., λ=30 mm), each antenna needs an area of at least a quarter wavelength (i.e., $\lambda/4$=7.5 mm) by a quarter wavelength (i.e., $\lambda/4$=7.5 mm) to receive the transmitted signals. As illustrated in FIG. **1**B, antennas **12-18** in front surface **104** may each have a square shape having dimensions of 7.5 mm by 7.5 mm, for example. In one implementation, each adjacent pair of antennas **12-18** may be separated by a distance of a multiple integer of the quarter wavelength (i.e., $n*\lambda/4$), such as 7.5 mm, 15 mm, 22.5 mm and etc. In general, the performance of the phased array antenna panel improves with the number of antennas **12-18** on front surface **104**.

In the present implementation, the phased array antenna panel is a flat panel array employing antennas **12-18**, where antennas **12-18** are coupled to associated active circuits to form a beam for reception (or transmission). In one implementation, the beam is formed fully electronically by means of phase control devices associated with antennas **12-18**. Thus, phased array antenna panel **100** can provide fully electronic beamforming without the use of mechanical parts.

As illustrated in FIG. **1**B, RF front end chips **106***a* through **106***p*, and antennas **12***a* through **12***p*, **14***a* through **14***p*, **16***a* through **16***p*, and **18***a* through **18***p*, are divided into respective antenna segments **111**, **113**, **115**, and **117**. As further illustrated in FIG. **1**B, antenna segment **111** includes front end unit **105***a* having RF front end chip **106***a* coupled to antennas **12***a*, **14***a*, **16***a*, and **18***a*, front end unit **105***b* having RF front end chip **106***b* coupled to antennas **12***b*, **14***b*, **16***b*, and **18***b*, front end unit **105***c* having RF front end chip **106***c* coupled to antennas **12***c*, **14***c*, **16***c*, and **18***c*, and front end unit **105***d* having RF front end chip **106***d* coupled to antennas **12***d*, **14***d*, **16***d*, and **18***d*. Antenna segment **113** includes similar front end units having RF front end chip **106***e* coupled to antennas **12***e*, **14***e*, **16***e*, and **18***e*, RF front end chip **106***f* coupled to antennas **12***f*, **14***f*, **16***f*, and **18***f*, RF front end chip **106***g* coupled to antennas **12***g*, **14***g*, **16***g*, and **18***g*, and RF front end chip **106***h* coupled to antennas **12***h*, **14***h*, **16***h*, and **18***h*. Antenna segment **115** also includes similar front end units having RF front end chip **106***i* coupled to antennas **12***i*, **14***i*, **16***i*, and **18***i*, RF front end chip **106***j* coupled to antennas **12***j*, **14***j*, **16***j*, and **18***j*, RF front end chip **106***k* coupled to antennas **12***k*, **14***k*, **16***k*, and **18***k*, and RF front end chip **106***l* coupled to antennas **12***l*, **14***l*, **16***l*, and **18***l*. Antenna segment **117** also includes similar front end units having RF front end chip **106***m* coupled to antennas **12***m*, **14***m*, **16***m*, and **18***m*, RF front end chip **106***n* coupled to antennas **12***n*, **14***n*, **16***n*, and **18***n*, RF front end chip **106***o* coupled to antennas **12***o*, **14***o*, **16***o*, and **18***o*, and RF front end chip **106***p* coupled to antennas **12***p*, **14***p*, **16***p*, and **18***p*.

As illustrated in FIG. **1**B, master chip **108** is configured to drive in parallel control buses **110***a*, **110***b*, **110***c*, and **110***d* coupled to antenna segments **111**, **113**, **115**, and **117**, respectively. For example, control bus **110***a* is coupled to RF front end chips **106***a*, **106***b*, **106***c*, and **106***d* in antenna segment **111** to provide phase shift signals and amplitude control signals to the corresponding antennas coupled to each of RF front end chips **106***a*, **106***b*, **106***c*, and **106***d*. Control buses **110***b*, **110***c*, and **110***d* are configured to perform similar functions as control bus **110***a*. In the present implementation, master chip **180** and antenna segments **111**, **113**, **115**, and **117** having RF front end chips **106***a* through **106***p* and antennas **12-18** are all integrated on a single printed circuit board.

It should be understood that layout diagram **190** in FIG. **1**B is intended to show a simplified phased array antenna panel according to the present inventive concepts. In one implementation, master chip **180** may be configured to control a total of 2000 antennas disposed in ten antenna segments. In this implementation, master chip **180** may be configured to drive in parallel ten control buses, where each control bus is coupled to a respective antenna segment, where each antenna segment has a set of 50 RF front end chips and a group of 200 antennas are in each antenna segment; thus, each RF front end chip is coupled to four antennas. Even though this implementation describes each RF front end chip coupled to four antennas, this implementation is merely an example. An RF front end chip may be coupled to any number of antennas, particularly a number of antennas ranging from three to sixteen.

FIG. **2** illustrates a functional block diagram of a portion of an exemplary phased array antenna panel according to one implementation of the present application. In the present implementation, front end unit **205***a* may correspond to front end unit **105***a* in FIG. **1**B of the present application. As illustrated in FIG. **2**, front end unit **205***a* includes antennas **22***a*, **24***a*, **26***a*, and **28***a* coupled to RF front end chip **206***a*, where antennas **22***a*, **24***a*, **26***a*, and **28***a* and RF front end chip **206***a* may correspond to antennas **12***a*, **14***a*, **16***a*, and **18***a* and RF front end chip **106***a*, respectively, in FIG. **1**B.

In the present implementation, antennas **22***a*, **24***a*, **26***a*, and **28***a* may be configured to receive signals from one or more commercial geostationary communication satellites, for example, which typically employ circularly polarized or linearly polarized signals defined at the satellite with a horizontally-polarized (H) signal having its electric-field oriented parallel with the equatorial plane and a vertically-polarized (V) signal having its electric-field oriented perpendicular to the equatorial plane. As illustrated in FIG. **2**, each of antennas **22***a*, **24***a*, **26***a*, and **28***a* is configured to provide an H output and a V output to RF front end chip **206***a*.

For example, antenna **22***a* provides linearly polarized signal **208***a*, having horizontally-polarized signal H**22***a* and vertically-polarized signal V**22***a*, to RF front end chip **206***a*. Antenna **24***a* provides linearly polarized signal **208***b*, having horizontally-polarized signal H**24***a* and vertically-polarized signal V**24***a*, to RF front end chip **206***a*. Antenna **26***a* provides linearly polarized signal **208***c*, having horizontally-polarized signal H**26***a* and vertically-polarized signal V**26***a*, to RF front end chip **206***a*. Antenna **28***a* provides linearly polarized signal **208***d*, having horizontally-polarized signal H**28***a* and vertically-polarized signal V**28***a*, to RF front end chip **206***a*.

As illustrated in FIG. **2**, horizontally-polarized signal H**22***a* from antenna **22***a* is provided to a receiving circuit having low noise amplifier (LNA) **222***a*, phase shifter **224***a* and variable gain amplifier (VGA) **226***a*, where LNA **222***a* is configured to generate an output to phase shifter **224***a*, and phase shifter **224***a* is configured to generate an output to VGA **226***a*. In addition, vertically-polarized signal V**22***a* from antenna **22***a* is provided to a receiving circuit including low noise amplifier (LNA) **222***b*, phase shifter **224***b* and variable gain amplifier (VGA) **226***b*, where LNA **222***b* is configured to generate an output to phase shifter **224***b*, and phase shifter **224***b* is configured to generate an output to VGA **226***b*.

As shown in FIG. **2**, horizontally-polarized signal H**24***a* from antenna **24***a* is provided to a receiving circuit having low noise amplifier (LNA) **222***c*, phase shifter **224***c* and variable gain amplifier (VGA) **226***c*, where LNA **222***c* is configured to generate an output to phase shifter **224***c*, and phase shifter **224***c* is configured to generate an output to VGA **226***c*. In addition, vertically-polarized signal V**24***a* from antenna **24***a* is provided to a receiving circuit including low noise amplifier (LNA) **222***d*, phase shifter **224***d* and variable gain amplifier (VGA) **226***d*, where LNA **222***d* is configured to generate an output to phase shifter **224***d*, and phase shifter **224***d* is configured to generate an output to VGA **226***d*.

As illustrated in FIG. **2**, horizontally-polarized signal H**26***a* from antenna **26***a* is provided to a receiving circuit having low noise amplifier (LNA) **222***e*, phase shifter **224***e* and variable gain amplifier (VGA) **226***e*, where LNA **222***e* is configured to generate an output to phase shifter **224***e*, and phase shifter **224***e* is configured to generate an output to VGA **226***e*. In addition, vertically-polarized signal V**26***a* from antenna **26***a* is provided to a receiving circuit including low noise amplifier (LNA) **222***f*, phase shifter **224***f* and variable gain amplifier (VGA) **226***f*, where LNA **222***f* is configured to generate an output to phase shifter **224***f*, and phase shifter **224***f* is configured to generate an output to VGA **226***f*.

As further shown in FIG. **2**, horizontally-polarized signal H**28***a* from antenna **28***a* is provided to a receiving circuit having low noise amplifier (LNA) **222***g*, phase shifter **224***g* and variable gain amplifier (VGA) **226***g*, where LNA **222***g* is configured to generate an output to phase shifter **224***g*, and phase shifter **224***g* is configured to generate an output to VGA **226***g*. In addition, vertically-polarized signal V**28***a* from antenna **28***a* is provided to a receiving circuit including low noise amplifier (LNA) **222***h*, phase shifter **224***h* and variable gain amplifier (VGA) **226***h*, where LNA **222***h* is configured to generate an output to phase shifter **224***h*, and phase shifter **224***h* is configured to generate an output to VGA **226***h*.

As further illustrated in FIG. **2**, control bus **210***a*, which may correspond to control bus **110***a* in FIG. **1**B, is provided to RF front end chip **206***a*, where control bus **210***a* is configured to provide phase shift signals to phase shifters **224***a*, **224***b*, **224***c*, **224***d*, **224***e*, **224***f*, **224***g*, and **224***h* in RF front end chip **206***a* to cause a phase shift in at least one of these phase shifters, and to provide amplitude control signals to VGAs **226***a*, **226***b*, **226***c*, **226***d*, **226***e*, **226***f*, **226***g*, and **226***h*, and optionally to LNAs **222***a*, **222***b*, **222***c*, **222***d*, **222***e*, **222***f*, **222***g*, and **222***h* in RF front end chip **206***a* to cause an amplitude change in at least one of the linearly polarized signals received from antennas **22***a*, **24***a*, **26***a*, and **28***a*. It should be noted that control bus **210***a* is also provided to other front end units, such as front end units **105***b*, **105***c*, and **105***d* in segment **111** of FIG. **1**B. In one implementation, at least one of the phase shift signals carried by control bus **210***a* is configured to cause a phase shift in at least one linearly polarized signal, e.g., horizontally-polarized signals H**22***a* through H**28***a* and vertically-polarized signals V**22***a* through V**28***a*, received from a corresponding antenna, e.g., antennas **22***a*, **24***a*, **26***a*, and **28***a*.

In one implementation, amplified and phase shifted horizontally-polarized signals H'**22***a*, H'**24***a*, H'**26***a*, and H'**28***a* in front end unit **205***a*, and other amplified and phase shifted horizontally-polarized signals from the other front end units, e.g. front end units **105***b*, **105***c*, and **105***d* as well as front end units in antenna segments **113**, **115**, and **117** shown in FIG. **1**B, may be provided to a summation block (not explicitly shown in FIG. **2**), that is configured to sum all of the powers of the amplified and phase shifted horizontally-polarized signals, and combine all of the phases of the amplified and phase shifted horizontally-polarized signals, to provide an H-combined output to a master chip such as master chip **180** in FIG. **1**. Similarly, amplified and phase shifted vertically-polarized signals V'**22***a*, V'**24***a*, V'**26***a*, and V'**28***a* in front end unit **205***a*, and other amplified and phase shifted vertically-polarized signals from the other front end units, e.g. front end units **105***b*, **105***c*, and **105***d* as well as front end units in antenna segments **113**, **115**, and **117** shown in FIG. **1**B, may be provided to a summation block (not explicitly shown in FIG. **2**), that is configured to sum all of the powers of the amplified and phase shifted horizontally-polarized signals, and combine all of the phases of the amplified and phase shifted horizontally-polarized signals, to provide a V-combined output to a master chip such as master chip **180** in FIG. **1**.

FIG. **3**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application. As illustrated in FIG. **3**A, exemplary phased array antenna panel **300** includes substrate **302**, antennas **312**, antenna rows **330***a*, **330***b*, **330***c*, **330***d*, **330***e*, **330***f*, **330***g*, and **330***h*, collectively referred to as antenna rows **330**, and row-end antennas **332***a*, **332***b*, **332***c*, **332***d*, **332***e*, **332***f*, **332***g*, and **332***h*, collectively referred to as row-end antennas **332**. Some features discussed in conjunction with the layout diagram of FIG. **1**B, such as a master chip, control and data buses, and RF front end chips, are omitted in FIG. **3**A for the purposes of clarity.

As illustrated in FIG. **3**A, antennas **312** may be arranged on the top surface of substrate **302** in antenna rows **330**. In one implementation, the distance between one antenna and an adjacent antenna in each one of antenna rows **330** is a fixed distance, such as a quarter wavelength (i.e., λ/4). As illustrated in FIG. **3**A, antenna rows **330** are rows of fourteen antennas **312**. In other implementations, antenna rows **330** may be rows of twelve antennas, or rows of sixteen antennas, or any other number of antennas. Multiple antenna rows **330** may be arranged on substrate **302** of phased array antenna panel **300**. In one implementation, the distance between adjacent antenna rows is a fixed distance. As illustrated in FIG. **3**A, a fixed distance D**1** separates antenna row **330***a* from adjacent antenna row **330***b*, with no antennas therebetween. In one implementation, distance D**1** may be greater than a quarter wavelength (i.e., greater than 214).

FIG. **3**B illustrates a cross-sectional view of a portion of phased array antenna panel **300**, corresponding to cross-section **3**B-**3**B shown in FIG. **3**A. As illustrated in FIG. **3**B, antenna rows **330***a*, **330***b*, **330***c*, **330***d*, and **330***e* have respective row-end antennas **332***a*, **332***b*, **332***c*, **332***d*, and **332***e* attached respectively to slanting mechanisms **340***a*, **340***b*, **340***c*, **340***d*, and **340***e*, collectively referred to as slanting mechanisms **340**. Slanting mechanisms **340** may be actuators. In one implementation, slanting mechanisms **340** may be millimeter-scale piezo-actuators, such as prefabricated tip/tilt piezo-actuators having diameters of, for example, 6.4 millimeters and heights of 8.3 millimeters. Alternatively, by way of other examples, prefabricated stack piezo-actuators having dimensions of, for example, 2 millimeters by 3 millimeters by 5 millimeters (2 mm×3 mm×5 mm), in addition to other custom piezo-actuators can be used. In another implementation, slanting mechanisms **340** may be microelectromechanical systems (MEMS) actuators, such as electrostatic torsion plate or thermal torsion plate actuators. As illustrated in FIG. **3**B, slanting mechanism **340***a* may cause antenna row **330***a* to be slanted to a desired angle based on signals received from a master chip (not shown in FIG. **3**B). In the example provided by FIG. **3**B, antenna row **330***a* has been slanted by slanting mechanism **340***a*. However, the cross-sectional view provided by FIG. **3**B shows only slanted row-end antenna **332***a* of antenna row **330***a*, while the remaining antennas in antenna row **330***a* are directly behind row-end antenna **332***a* and thus cannot be seen in the cross-sectional view provided by FIG. **3**B.

The intended or desired angle of the slanted antenna row shown in FIG. **3**B may be exaggerated for the purposes of illustration. In one implementation, slanting mechanism **340***a* may cause antenna row **330***a* to be slanted to a desired angle utilizing one actuator for the entire row **330***a*. In another implementation, slanting mechanism **340***a* may cause antenna row **330***a* to be slanted to a desired angle utilizing one actuator for each antenna in row **330***a*. In one implementation, individual antennas in row **330***a* can be slanted to a desired angle that may be a different angle from angles to which other antennas in row **330***a* are slanted.

Slanting mechanism **340***a* may be attached to substrate **302**. A master chip (not shown in FIG. **3**B) may be configured to control the operation of slanting mechanism **340***a* by signals sent through traces, conductors, and/or vias in substrate **302**. For example, a master chip may control timing, direction, desired angle, and speed of slanting mechanism **340***a*. By causing an antenna row of phased array antenna panel **300** to be slanted in a desired angle, phased array antenna panel **300** can change the direction of an RF beam formed by phased array antenna panel **300**. Thus, in addition to the improved directionality attributable to the phase and amplitude control capabilities of phased array antenna panel **300**, further improvement and control over the directionality of phased array antenna panel **300** can be achieved by causing an antenna row to be slanted to a desired angle.

FIG. **4**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application. As illustrated in FIG. **4**A, exemplary phased array antenna panel **400** includes substrate **402**, antennas **412**, antenna rows **430***a*, **430***b*, **430***c*, **430***d*, **430***e*, **430***f*, **430***g*, and **430***h*, collectively referred to as antenna rows **430**, and row-end antennas **432***a*, **432***b*, **432***c*, **432***d*, **432***e*, **432***f*, **432***g*, and **432***h*, collectively referred to as row-end antennas **432**. FIG. **4**A represents another implementation of the present application where multiple antenna rows have been slanted, rather than only one row having been slanted—as was the case with respect to FIG. **3**A. Phased array antenna panel **400** in FIG. **4**A may have any of the configurations described above with respect to FIG. **3**A.

FIG. **4**B illustrates a cross-sectional view of a portion of phased array antenna panel **400**, corresponding to cross-section **4**B-**4**B shown in FIG. **4**A. As illustrated in FIG. **4**B, antenna rows **430***a*, **430***b*, **430***c*, **430***d*, and **430***e* have respective row-end antennas **432***a*, **432***b*, **432***c*, **432***d*, and **432***e*, attached respectively to slanting mechanisms **440***a*, **440***b*, **440***c*, **440***d*, and **440***e*, collectively referred to as slanting mechanisms **440**. Slanting mechanisms **440** may be actuators. In one implementation, slanting mechanisms **440** may be millimeter-scale piezo-actuators, such as prefabricated tip/tilt piezo-actuators having diameters of, for example, 6.4 millimeters and heights of 8.3 millimeters. Alternatively, by way of other examples, prefabricated stack piezo-actuators having dimensions of, for example, 2 millimeters by 3 millimeters by 5 millimeters (2 mm×3 mm×5 mm), in addition to other custom piezo-actuators can be used. In another implementation, slanting mechanisms **440** may be microelectromechanical systems (MEMS) actuators, such as electrostatic torsion plate or thermal torsion plate actuators.

In the example provided by FIG. **4**B, multiple antenna rows have been slanted by slanting mechanisms **440**. Specifically, in FIG. **4**B antenna row **430***a* has been slanted by slanting mechanism **440***a*, antenna row **430***b* has been slanted by slanting mechanism **440***b*, antenna row **430***c* has been slanted by slanting mechanism **440***c*, antenna row **430***d* has been slanted by slanting mechanism **440***d*, and antenna row **430***e* has been slanted by slanting mechanism **440***e*. However, the cross-sectional view provided by FIG. **4**B shows only slanted row-end antennas **432***a*, **432***b*, **432***c*, **432***d*, and **432***e* of corresponding antenna rows **430***a*, **430***b*, **430***c*, **430***d*, and **430***e*, while the remaining antennas in antenna rows **430***a*, **430***b*, **430***c*, **430***d*, and **430***e* are directly behind row-end antennas **432***a*, **432***b*, **432***c*, **432***d*, and **432***e* and thus cannot be seen in the cross-sectional view provided by FIG. **4**B.

The intended or desired angle of the slanted antenna rows shown in FIG. **4**B may be exaggerated for the purposes of illustration. In one implementation, each of antenna rows **430** can be slanted to the same desired angle. In another implementation, each of antenna rows **430** can be slanted to a desired angle that may be a different angle from angles to which other antenna rows are slanted. In one implementation, slanting mechanisms **440** may cause antenna rows **430** to be slanted to a desired angle utilizing one actuator for each of antenna rows **430**. In another implementation, slanting mechanisms **440** may cause antenna rows **430** to be slanted to a desired angle utilizing one actuator for each antenna in each of antenna rows **430**. In one implementation, individual antennas in each of antenna rows **430** can be slanted to a desired angle that may be a different angle from angles to which other antennas in the same row are slanted.

FIG. **4**B further illustrates wireless communication system **460** and RF beams **462**. As illustrated in FIG. **4**B, phased array antenna panel **400** may form RF beams **462**. Wireless communication system **460** which may be, for example, a satellite having a transceiver, is in bi-directional communication with phased array antenna panel **400** through RF beams **462**. A master chip (not shown in FIG. **4**B) may be configured to control the operation of slanting mechanisms **440** at least in part based upon the position of wireless communication system **460** relative to phased array antenna panel **400**. In FIG. **4**B, antenna rows **430** have been slanted in a desired angle by slanting mechanisms **440**, thereby changing the direction of RF beams **462** formed by phased array antenna panel **400**, such that the direction of RF beams **462** is substantially perpendicular to antenna rows **430***a*, **430***b*, **430***c*, **430***d*, and **430***e* in phased array antenna panel **400**. In other implementations, RF beams **462** may have any other direction relative to antenna rows **430***a*, **430***b*, **430***c*, **430***d*, and **430***e*. In one implementation, wireless communication system **460** may be a transmitter and phased array antenna panel **400** may be a receiver. In another implementation, wireless communication system **460** may be a receiver and phased array antenna panel **400** may be a transmitter.

FIG. **5**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application. As illustrated in FIG. **5**A, exemplary phased array antenna panel **500** includes substrate **502**, antennas **512**, antenna rows **530***a*, **530***b*, **530***c*, **530***d*, **530***e*, **530***f*, **530***g*, and **530***h*, collectively referred to as antenna rows **530**, row-end antennas **532***a*, **532***b*, **532***c*, **532***d*, **532***e*, **532***f*, **532***g*, and **532***h*, and lenses **550***a*, **550***b*, **550***c*, **550***d*, **550***e*, **550***f*, **550***g*, and **550***h*, collectively referred to as lenses **550**.

Phased array antenna panel **500** in FIG. **5**A may have any of the configurations described above, however, in the example provided by FIG. **5**A, lenses **550** are situated over phased array antenna panel **500**. In FIG. **5**A, phased array antenna panel **500** is seen through lenses **550**. As further shown in FIG. **5**A, lenses **550** are narrow, elongated, and used with antenna rows **530**. Thus, lenses **550** are referred to as row-shaped lenses in the present application. In some implementations of the present application, one lens may correspond to more than one antenna row (i.e. one lens can be wide enough to cover two or more antenna rows), and conversely not all antenna rows must have a corresponding lens (i.e. some antenna rows may have no corresponding lens situated thereon). Row-shaped lenses **550** may be dielectric lenses, e.g., made of polystyrene or Lucite® and polyethylene. In other implementations, row-shaped lenses **550** may be Fresnel zone plate lenses, or a metallic waveguide lenses. In yet other implementations, row-shaped lenses **550** may be flat (or substantially flat) lenses that include perforations, such as slots or holes. Row-shaped lenses **550** may be separate lenses, each individually placed over phased array antenna panel **500**. Alternatively, row-shaped lenses **550** may be placed over phased array antenna panel **500** as a lens array, where one substrate holds together multiple lenses **550**.

Row-shaped lenses **550** may increase gains of their corresponding antenna rows **530** in phased array antenna panel **500** by focusing an incoming RF beam onto their corresponding antenna rows **530**. A master chip (not shown in FIG. **5**A) may be configured to control the operation of antenna rows **530**, and to receive a combined output, as stated above. Thus, by increasing the gain of each one of, or selected ones of, antenna rows **530**, the total gain of the phased array antenna panel **500** is increased, resulting in an increase in the power of RF signals being processed by the phased array antenna panel **500**, without increasing the area of the phased array antenna panel or the number of antennas therein.

FIG. **5**B illustrates a cross-sectional view of a portion of phased array antenna panel **500**, corresponding to cross-section **5**B-**5**B shown in FIG. **5**A. As illustrated in FIG. **5**B, lenses **550***a*, **550***b*, **550***c*, **550***d*, and **550***e* are situated respectively over corresponding antenna rows **530***a*, **530***b*, **530***c*, **530***d*, and **530***e*. Antenna rows **530***a*, **530***b*, **530***c*, **530***d*, and **530***e* have respective row-end antennas **532***a*, **532***b*, **532***c*, **532***d*, and **532***e* attached respectively to slanting mechanisms **540***a*, **540***b*, **540***c*, **540***d*, and **540***e*, collectively referred to as slanting mechanisms **540**. Slanting mechanisms **540** may be actuators. In one implementation, slanting mechanisms **540** may be millimeter-scale piezo-actuators, such as prefabricated tip/tilt piezo-actuators having diameters of, for example, 6.4 millimeters and heights of 8.3 millimeters. Alternatively, by way of other examples, prefabricated stack piezo-actuators having dimensions of, for example, 2 millimeters by 3 millimeters by 5 millimeters (2 mm×3 mm×5 mm), in addition to other custom piezo-actuators can be used. In another implementation, slanting mechanisms **540** may be microelectromechanical systems (MEMS) actuators, such as electrostatic torsion plate or thermal torsion plate actuators. As illustrated in FIG. **5**B, slanting mechanism **540***a* may cause antenna row **530***a* to be slanted to a desired angle based on signals received from a master chip (not shown in FIG. **5**B). In the example provided by FIG. **5**B, antenna row **530***a* has been slanted by slanting mechanism **540***a*. However, the cross-sectional view provided by FIG. **5**B shows only slanted row-end antenna **532***a* of antenna row **530***a*, while the remaining antennas in antenna row **530***a* are directly behind row-end antenna **532***a* and thus cannot be seen in the cross-sectional view provided by FIG. **5**B.

The intended or desired angle of the slanted antenna row shown in FIG. **5**B may be exaggerated for the purposes of illustration. In one implementation, slanting mechanism **540***a* may cause antenna row **530***a* to be slanted to a desired angle utilizing one actuator for the entire row **530***a*. In another implementation, slanting mechanism **540***a* may cause antenna row **530***a* to be slanted to a desired angle utilizing one actuator for each antenna in row **530***a*. In one implementation, individual antennas in row **530***a* can be slanted to a desired angle that may be a different angle from angles to which other antennas in row **530***a* are slanted.

In the example provided by FIG. **5**B, row-shaped lens **550***a* has been slanted to a desired angle. Various connections and components related to row-shaped lens **550***a* are omitted in FIG. **5**B for the purposes of clarity. In one implementation, row-shaped lens **550***a* may be controlled by slanting mechanism **540***a*, such that slanting mechanism **540***a* may cause both antenna row **530***a* and row-shaped lens **550***a* to be slanted to a desired angle based on signals received from a master chip (not shown in FIG. **5**B). In another implementation, row-shaped lens **550***a* may be controlled by another slanting mechanism that is distinct from slanting mechanisms **540**. For example, row-shaped lens **550***a* may be attached to a plurality of stack piezo-actuators that are situated adjacent to antennas in antenna row **530***a* and attached to substrate **502**. In yet another implementation, row-shaped lens **550***a* may be mounted on antennas in antenna row **530***a*, such that slanting the antennas in antenna row **530***a* may cause row-shaped lens **550***a* to be slanted to a desired angle.

The intended or desired angle of the slanted row-shaped lens shown in FIG. **5**B may be exaggerated for the purposes of illustration. In one implementation, row-shaped lens **550***a* can be maintained substantially parallel with antenna row **530***a*, and thus be slanted to substantially the same angle as antenna row **530***a*. In one implementation, row-shaped lens **550***a* can be slanted to a desired angle that may be a different angle from an angle to which antenna row **530***a* is slanted. In one implementation, multiple lenses can be situated over antenna row **530***a*, and individual lenses can be slanted to a desired angle that may be a different angle from angles to which other lenses over antenna row **530***a* are slanted.

A master chip (not shown in FIG. **5**B) may be configured to control the slanting of row-shaped lens **550***a* by signals sent through traces, conductors, and/or vias in substrate **502**. For example, a master chip may control timing, direction, desired angle, and speed of the mechanisms that cause row-shaped lens **550***a* to be slanted. By causing a row-shaped lens and a corresponding antenna row of phased array antenna panel **500** to be slanted in a desired angle, phased array antenna panel **500** can change the direction of an RF beam formed by phased array antenna panel **500**, while also increasing a total gain of phased array antenna panel **500**. Thus, in addition to the improved directionality attributable to the phase and amplitude control capabilities of phased array antenna panel **500**, further improvement and control over the directionality of phased array antenna panel **500** can be achieved by causing a row-shaped lens and a corresponding antenna row to be slanted to a desired angle.

FIG. **6**A illustrates a top view of a portion of an exemplary phased array antenna panel according to one implementation of the present application. As illustrated in FIG. **6**A, exemplary phased array antenna panel **600** includes substrate **602**, antennas **612**, antenna rows **630***a*, **630***b*, **630***c*, **630***d*, **630***e*, **630***f*, **630***g*, and **630***h*, collectively referred to as antenna rows **630**, row-end antennas **632***a*, **632***b*, **632***c*, **632***d*, **632***e*, **632***f*, **632***g*, and **632***h*, collectively referred to as row-end antennas **632**, and row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, **650***e*, **650***f*, **650***g*, and **650***h*, collectively referred to as row-shaped lenses **650**. FIG. **6**A represents another implementation of the present application where multiple row-shaped lenses have been slanted, rather than only one row-shaped lens having been slanted—as was the case with respect to FIG. **5**A. Phased array antenna panel **600** in FIG. **6**A may have any of the configurations described above with respect to FIG. **5**A.

FIG. **6**B illustrates a cross-sectional view of a portion of phased array antenna panel **600**, corresponding to cross-section **6**B-**6**B shown in FIG. **6**A. As illustrated in FIG. **6**B, lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* are situated respectively over corresponding antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e*. Antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* have respective row-end antennas **632***a*, **632***b*, **632***c*, **632***d*, and **632***e* attached respectively to slanting mechanisms **640***a*, **640***b*, **640***c*, **640***d*, and **640***e*, collectively referred to as slanting mechanisms **640**. Slanting mechanisms **640** may be actuators. In one implementation, slanting mechanisms **640** may be millimeter-scale piezo-actuators, such as prefabricated tip/tilt piezo-actuators having diameters of, for example, 6.4 millimeters and heights of 8.3 millimeters. Alternatively, by way of other examples, prefabricated stack piezo-actuators having dimensions of, for example, 2 millimeters by 3 millimeters by 5 millimeters (2 mm×3 mm×5 mm), in addition to other custom piezo-actuators can be used. In another implementation, slanting mechanisms **640** may be microelectromechanical systems (MEMS) actuators, such as electrostatic torsion plate or thermal torsion plate actuators.

In the example provided by FIG. **6**B, multiple antenna rows have been slanted by slanting mechanisms **640**. Specifically, in FIG. **6**B antenna row **630***a* has been slanted by slanting mechanism **640***a*, antenna row **630***b* has been slanted by slanting mechanism **640***b*, antenna row **630***c* has been slanted by slanting mechanism **640***c*, antenna row **630***d* has been slanted by slanting mechanism **640***d*, and antenna row **630***e* has been slanted by slanting mechanism **640***e*. However, the cross-sectional view provided by FIG. **6**B shows only slanted row-end antennas **632***a*, **632***b*, **632***c*, **632***d*, and **632***e* of corresponding antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e*, while the remaining antennas in antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* are directly behind row-end antennas **632***a*, **632***b*, **632***c*, **632***d*, and **632***e* and thus cannot be seen in the cross-sectional view provided by FIG. **6**B.

The intended or desired angle of the slanted antenna rows shown in FIG. **6**B may be exaggerated for the purposes of illustration. In one implementation, each of antenna rows **630** can be slanted to the same desired angle. In another implementation, each of antenna rows **630** can be slanted to a desired angle that may be a different angle from angles to which other antenna rows are slanted. In one implementation, slanting mechanisms **640** may cause antenna rows **630** to be slanted to a desired angle utilizing one actuator for each of antenna rows **630**. In another implementation, slanting mechanisms **640** may cause antenna rows **630** to be slanted to a desired angle utilizing one actuator for each antenna in each of antenna rows **630**. In one implementation, individual antennas in each of antenna rows **630** can be slanted to a desired angle that may be a different angle from angles to which other antennas in the same row are slanted.

In the example provided by FIG. **6**B, multiple row-shaped lenses have been slanted to a desired angle. Specifically, row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* have been slanted. Various attachments of row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* are omitted in FIG. **6**B for the purposes of clarity. In one implementation, row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* may be respectively controlled by slanting mechanisms **640***a*, **640***b*, **640***c*, **640***d*, and **640***e*, such that slanting mechanisms **640***a*, **640***b*, **640***c*, **640***d*, and **640***e* may respectively cause antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* and corresponding row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* to be slanted to a desired angle based on signals received from a master chip (not shown in FIG. **6**B). In another implementation, row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* may be controlled by other slanting mechanisms that are distinct from slanting mechanisms **640**. For example, each of row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* may be attached to a plurality of stack piezo-actuators that are arranged around antennas in corresponding antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* and attached to substrate **602**. In yet another implementation, row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* may be respectively mounted on antennas in antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e*, such that slanting the antennas in antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* may respectively cause row-shaped lenses **650***a*, **650***b*, **650***c*, **650***d*, and **650***e* to be slanted to a desired angle.

The intended or desired angle of the slanted row-shaped lenses shown in FIG. **6**B may be exaggerated for the purposes of illustration. In one implementation, row-shaped lenses **650** can be maintained substantially parallel with antenna rows **630**, and thus be slanted to substantially the same angle as antenna rows **630**. In another implementation, each of row-shaped lenses **650** can be slanted to a desired angle that may be a different angle from angles to which other row-shaped lenses are slanted. In one implementation, row-shaped lenses **650** can be slanted to a desired angle that may be a different angle from an angle to which antenna rows **630** are slanted. In one implementation, multiple lenses can be situated over each of antenna rows **630**, and individual lenses can be slanted to a desired angle that may be a different angle from angles to which other lenses over the same row are slanted.

FIG. **6**B further shows wireless communication system **660** and RF beams **662**. As illustrated in FIG. **6**B, phased array antenna panel **600** may form RF beams **662**. Wireless communication system **660** which may be for example, a satellite having a transceiver, is in bi-directional communication with phased array antenna panel **600** through RF beams **662**. A master chip (not shown in FIG. **6**B) may be configured to control the operation of slanting mechanisms **640** at least in part based upon the position of wireless communication system **660** relative to phased array antenna panel **600**. In FIG. **6**B, antenna rows **630** and row-shaped lenses **650** have been slanted in a desired angle by slanting mechanisms **640**, thereby changing the direction of RF beams **662** formed by phased array antenna panel **600**, such that the direction of RF beams **662** is substantially perpendicular to antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e* in phased array antenna panel **600**. In other implementations, RF beams **662** may have any other direction relative to antenna rows **630***a*, **630***b*, **630***c*, **630***d*, and **630***e*. In one implementation, wireless communication system **660** may be a transmitter and phased array antenna panel **600** may be a receiver. In another implementation, wireless communication system **660** may be a receiver and phased array antenna panel **600** may be a transmitter.

Thus, various implementations of the present application result in an increased directionality of a wireless receiver employing a phased array antenna panel without increasing the number of antennas, phase shifters or front end chips of the phased array antennal panel.

From the above description it is manifest that various techniques can be used for implementing the concepts described in the present application without departing from the scope of those concepts. Moreover, while the concepts have been described with specific reference to certain implementations, a person of ordinary skill in the art would recognize that changes can be made in form and detail without departing from the scope of those concepts. As such, the described implementations are to be considered in all respects as illustrative and not restrictive. It should also be understood that the present application is not limited to the particular implementations described above, but many rearrangements, modifications, and substitutions are possible without departing from the scope of the present disclosure.

The invention claimed is:

1. A phased array antenna panel comprising:

a plurality of antennas arranged in a plurality of antenna rows;

a plurality of row-shaped lenses;

at least one of said plurality of row-shaped lenses having a corresponding antenna row in said plurality of antenna rows;

said at least one of said plurality of row-shaped lenses providing a gain to said corresponding antenna row so as to increase a total gain of said phased array antenna panel;

said at least one of said plurality of row-shaped lenses and said corresponding antenna row being configured to be slanted in a desired angle based on signals received from a master chip in said phased array antenna panel, thereby changing a direction of an RF beam formed by said phased array antenna panel.

2. The phased array antenna panel of claim **1**, further comprising:

a plurality of radio frequency (RF) front end chips;

wherein said master chip provides phase shift signals for said plurality of antennas through said plurality of RF front end chips.

3. The phased array antenna panel of claim **1**, further comprising:

a plurality of radio frequency (RF) front end chips;

wherein said master chip provides amplitude control signals for said plurality of antennas through said plurality of RF front end chips.

4. The phased array antenna panel of claim **1**, wherein said plurality of antennas and said master chip are integrated in a single printed circuit board (PCB).

5. The phased array antenna panel of claim **1**, wherein said least one of said plurality of row-shaped lenses is configured to be slanted while being maintained in parallel with said corresponding antenna row in said plurality of antenna rows.

6. The phased array antenna panel of claim **1**, wherein said corresponding antenna row in said plurality of antenna rows is configured to be slanted by a piezo-actuator.

7. The phased array antenna panel of claim **1**, wherein said corresponding antenna row in said plurality of antenna rows is configured to be slanted by an electrostatic actuator.

8. The phased array antenna panel of claim **1**, wherein said corresponding antenna row in said plurality of antenna rows is configured to be slanted by a microelectromechanical systems (MEMS) actuator.

9. The phased array antenna panel of claim **1**, wherein said phased array antenna panel is a receiver, and said direction of said RF beam is substantially perpendicular to said corresponding antenna row.

10. The phased array antenna panel of claim **1**, wherein said phased array antenna panel is a transmitter, and said direction of said RF beam is substantially perpendicular to said corresponding antenna row.

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